A METHOD AND APPARATUS FOR DEMULTIPLEXING HIGH BIT RATE OPTICAL SIGNALS ON A DENSE WAVELENGTH GRID

Field of the Invention

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[01]   The present invention relates to a method and an apparatus for demultiplexing high bit rate optical signals on a dense wavelength grid.

10   **Background of the Invention**

[02]   In optical communications, wavelength division multiplexing (WDM) is used for increasing the transmission capacity of a single optical fibre. The vast expansion in demand for communications bandwidth is pushing fibre transmission technology to its physical limits. Increased transmission capacity is obtained by increasing the transmission data rate through the fibre. Current transmission data rates are approaching the limits of opto-electronic components. Increased transmission capacity is also obtained by reducing the channel frequency spacing in a WDM optical fibre link. Such WDM links are referred to as DWDM (Dense Wavelength Division Multiplexing) because the density of the wavelength channels per unit wavelength is higher than in conventional WDM. The use of both higher data rates and closer channel spacing puts severe demands on the performance of the optical demultiplexer which can limit the optical capacity of the transmission link. For example, in current WDM links, the optical signals are transmitted at 10 Gbit/s on wavelength channels spaced at frequency intervals of 100 GHz. It is planned to increase the data rate to 40 Gbit/s, which concomitantly increases the bandwidth of the wavelength channel. The result is that in the wavelength domain, the linewidths of adjacent wavelength channels overlap making it difficult to demultiplex the individual wavelength channels without incurring an unacceptable loss in data information.

[03]   To better appreciate the problems consider the following. As the modulation bit rate is increased from 10 GHz to 40 GHz, the bandwidth ΔB of a channel signal increases; the relationship between the light pulse width Δt and signal bandwidth ΔB is $\Delta t = 1/\Delta B$. In the case

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of a 40 GHz signal using a RZ (return to zero) modulation format, the separation between the

pulses is 25 ps, but the pulse width, Δt, is only 12.5ps and consequently, the modulation

bandwidth ΔB is 80 GHz. The minimum modulated bandwidth of these signals is 60 GHz. Thus

theoretically, wavelength channels transmitting data at 40 GHz could be multiplexed together

5   onto a DWDM link in which the frequency separation is only 100 GHz. However, the

theoretical capacity of the WDM link is limited by the band pass and the environmental stability

of the optical filters used in demultiplexing. The available filter pass-band is determined by the

figure of merit, which is defined as the bandwidth at the 0.5 dB point divided by the bandwidth

at the 25 dB point and this is typically 0.4 to 0.5. Thus a high quality optical filter that could be

10   used to demultiplex the DWDM signals have a measured pass bandwidth of 50 GHz and net

bandwidth of only 25 GHz. Misalignment of the filter wavelength to the signal wavelengths due

to manufacturing tolerances and environmental factors such as ageing will reduce the available

bandwidth even further. Thus, demultiplexing this optical signal using prior art techniques

would result in unacceptable error rates and data loss.

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[04]   It is an object of the invention to provide a demultiplexer capable of demultiplexing high

bit-rate optical signals.

[05]   It is a further object of the invention to provide a demultiplexer capable of demultiplexing

20   optical signals in which the linewidths of adjacent channels overlap in the wavelength domain.

[06]   It is a further object of the invention to provide a low loss high bit-rate demultiplexer.

[07]   It is another object of the invention to provide a high bit-rate demultiplexer having a low

25   error rate.

Summary of the Invention

30   [08]   In accordance with the invention there is provided an optical demultiplexer for

demultiplexing an optical signal having a plurality of channels at a predetermined channel

2

spacing comprising demultiplexing means having a frequency spacing larger than the predetermined channel spacing for receiving the optical signal and for dividing the optical signal by wavelength into a plurality of wavelength streams broader than the predetermined channel spacing, time domain demultiplexing means for receiving one of the plurality of wavelength

5   streams and for dividing the one of the plurality of wavelength streams into a plurality of time domain demultiplexed wavelength streams, and optical filtering means for demultiplexing one of the plurality of time domain demultiplexed wavelength streams into a single channel.

[09]   In accordance with an embodiment of the invention the optical demultiplexer further

10   comprises splitting means for splitting the optical signal into at least two sub-signals before launching one of the sub-signals into the demultiplexing means.

[10]   In accordance with another embodiment of the present invention the optical demultiplexer further comprises clock recovery means for obtaining a clock signal from the one

15   of the plurality of wavelength streams and for providing the clock signal to the time domain demultiplexing means for dividing the one of the plurality of wavelength streams into a plurality of time domain demultiplexed wavelength streams in dependence upon the clock signal.

[11]   The invention further provides an optical demultiplexer for demultiplexing a multiplexed

20   N channel optical signal comprising splitting means for splitting the multiplexed N channel optical signal into a plurality of multiplexed N channel optical sub-signals, first demultiplexing means for coarse wavelength demultiplexing the plurality of multiplexed N channel optical sub-signals into M sub-signals, second demultiplexing means for time demultiplexing the M sub-signals into R sub-signals, and third demultiplexing means for wavelength demultiplexing the R

25   sub-signals into N single channels.

[12]   In accordance with an embodiment of the invention M is a smaller number than N.

[13]   In accordance with a further embodiment of the invention, the plurality of multiplexed N

30   channel optical sub-signals and the M sub-signals have a data rate B. The R sub-signals have a data rate C which is a lower than data rate B. Data rate B is equal to the sum of the data rates C

of all the R sub-signals of one of the plurality of multiplexed N channel optical sub-signals or the M sub-signals.

[14]   In accordance with another aspect of the invention there is provided a method for demultiplexing a high bit-rate signal on a dense optical grid comprising the steps of providing the high bit-rate signal including a plurality of wavelength channels at a predetermined channel spacing to a coarse wavelength demultiplexer, performing a coarse wavelength demultiplexing for dividing the high bit-rate signal into wavelength streams broader than the predetermined channel spacing, performing an optical time domain demultiplexing for dividing at least one of the wavelength streams into a plurality of time demultiplexed streams, and filtering at least one time demultiplexed stream through a wavelength filter for obtaining at least one individual wavelength channel.

[15]   The present invention has developed a method and an apparatus for demultiplexing very high bit rate signals which are multiplexed at close channel spacing. The invention has found that a demultiplexing method combining time and wavelength demultiplexing can be achieved within the practical limits of optical and electronic technology.

[16]   In accordance with the present invention there is provided a method for demultiplexing a high bit rate signal comprising a first coarse optical frequency demultiplexing step for separating signals of groups of channels, followed by a subsequent time domain demultiplexing step for providing sufficient signal separation within each group of channels to perform a third optical frequency domain demultiplexing step separating individual channel signals.

[17]   A preferred method in accordance with the present invention comprises a method for demultiplexing a high bit rate signal on a dense optical grid comprising the steps of :

      providing a signal including a plurality of wavelength channels having a predetermined channel spacing;

      performing a coarse wavelength demultiplexing of wavelength streams broader than the predetermined channel spacing;

      identifying a timing signal from the wavelength streams;

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performing an optical time domain demultiplexing for at least one of the wavelength streams with respect to the timing signal;

filtering the at least one time demultiplexed stream through a filter to obtain an output signals having the predetermined channel spacing.

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[18]   The method is further improved by initially splitting the signal into at least two streams and providing each stream into a separate coarse wavelength demultiplexer of different but overlapping wavelength ranges.

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Brief Description of the Drawings

[19]   Exemplary embodiments of the invention will now be described in conjunction with the drawings in which:

[20]   Fig. 1a is a flow chart to summarize the invention of demultiplexing a high bit-rate optical signal by triple stage demultiplexing;

[21]   Fig. 1 is a schematic illustration of the invention shown in an exemplary scale;

[22]   Fig. 2 is a graph illustrating exemplary signals at 40 Gbits/s and a filter response (for demonstration only) of intensity versus wavelength following a first wavelength demultiplexing step;

[23]   Fig. 3 is a graph illustrating exemplary signals at 40 Gbits/s of intensity versus time;

[24]   Fig. 4 is a graph illustrating the signal of Fig. 3 following the time domain demultiplexing step; and,

[25]   Fig. 5 is a graph illustrating the signal and the filter response of Fig. 2 following a final wavelength demultiplexing step.

Detailed Description of Preferred Embodiments

[26]   Reference is now made to Fig. 1a presenting a flow chart to summarize the invention of demultiplexing a high bit-rate optical signal by demultiplexing in three stages. The first and the

third stage are optical frequency domain demultiplexers and the second stage is an optical time domain demultiplexer. A multiplexed signal 1 having a plurality of wavelength channels λ_1 to λ_n is split into a number of data streams and each one is launched into a coarse wavelength demultiplexer 2. The number of data streams required depends on the ratio of the frequency

5   spacing of the coarse demultiplexer to the frequency spacing of the high bit-rate optical signal. The frequency spacing of the demultiplexer can be an integer or non-integer multiple of the channel spacing, but advantageously, the frequency spacing is some integral number i.e. twice the channel spacing of the high bit-rate signal. Furthermore, conveniently, the channel spacing has frequency spacing according to a standardized International Telecommunications Union

10 (ITU) frequency grid and the demultiplexer demultiplexes the optical signal according to the standardized ITU frequency grid. In this first stage of the demultiplexing, only those wavelength channels at the coarse demultiplexer frequency spacing are selected and demultiplexed from the input optical signal. The wavelength channels that lie in between the coarse demultiplexer frequency spacing are recovered by demultiplexing the other data streams obtained by splitting

15 the input signal before entering the coarse demultiplexer 2. The coarse wavelength demultiplexer 2 also has a demultiplexing bandwidth that is larger than the frequency spacing of the optical signal. This is necessary so that a bandwidth of the 40 GHz signal is not reduced in the demultiplexing process and all the information in the signal is retained. As a result, the signal outputs from the coarse wavelength demultiplexer 2 are not purely one wavelength

20 channel, but a demultiplexed light output contains significant amounts of the light from adjacent wavelength channels on either side of the demultiplexed channel. Each wavelength channel output from the coarse demultiplexer 2 is then passed through an optical time domain demultiplexer 3 which divides the high bit-rate wavelength streams into a number of time domain demultiplexed streams having lower bit-rates (sub-bit-rates). The wavelength streams

25 can be divided into any number of sub-bit-rates, however, the sum of the sub-bit-rates is equal to the bit-rate of the wavelength stream send into the time domain demultiplexer 3. The signal output from the time domain demultiplexer still contains light at the channel wavelength and the adjacent channels, however, the process of time domain demultiplexing has reduced the bit rate so that the data information is contained in a smaller bandwidth. The time domain demultiplexed

30 streams can now be passed through a narrow band wavelength filter 4 having a linewidth that is narrower than the frequency spacing between the channels of the high bit rate optical signal but

sufficiently broad to capture all the data information. In this way the wavelength-time domain demultiplexer demultiplexes the high bit rate DWDM optical signal into its separate individual wavelength channels λ_1 to λ_n, as denoted by reference numeral 5, with each wavelength channel comprising several lower bit rate channels.

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[27]   A demultiplexer in accordance with the present invention is shown schematically in Fig. 1. At 10 a signal of multiple wavelength channels at 40 Gbits/s spaced on a 50 GHz or 100 GHz optical network grid is divided by a 1:4 splitter 12 in the case of a 50 GHz channel spacing or a 1:2 splitter in the case of a 100 GHz channel spacing. As shown in Figure 2, the linewidths of

10   the individual wavelength channels of the optical signal overlap adjacent channels in the wavelength domain due to a high modulation rate of the optical signals. Figure 3 shows the 40 Gbit/s signal in the time domain; the optical pulses are spaced at 25 ps intervals and have a pulse width of 12.5 ps for a return-to-zero (RZ) modulation format. In the following description of this embodiment of the invention, the channel spacing of the input signal 10 is taken as 100 GHz. An

15   output signal 14 from the splitter 12 (1:2 in this case) is routed to a 200 GHz coarse wavelength demultiplexer 16. The coarse wavelength demultiplexer 16 demultiplexes every second wavelength channel from the optical signal input thereby producing at the outputs of the demultiplexer a sequence of wavelength channels spaced by 200 GHz. A typical 200 GHz demultiplexer has a measured bandwidth of 120 GHz and a net bandwidth of 80 GHz. Figure 2

20   shows the bandwidth of a typical filter in comparison to the linewidths of the wavelength channels. Since the bandwidth of the demultiplexer 16 approaches the 100 GHz channel spacing of the optical signal 10, each wavelength channel at the output of the demultiplexer 16 contains light not only at the channel wavelength but also light from the adjacent channels spaced at 100 GHz on either side. In the wavelength domain, the output from the coarse wavelength

25   demultiplexer 16 appears as a single wavelength at demultiplexed channel wavelength with smaller sidebands at wavelengths 100 GHz on either side of the channel wavelength. It is estimated that the 200 GHz demultiplexer attenuates the adjacent channels by only 5 to 10 dB which is insufficient isolation for the data to be detected with a low error rate.

30   [28]   Since the coarse wavelength demultiplexer 16 provides only one half of the wavelength channels contained in the input WDM optical signal 10, a second coarse wavelength

demultiplexer, not shown in Fig. 1, connected to the other output from the optical splitter 12 is used to provide the wavelength channels located in between the channel frequencies of the coarse wavelength demultiplexer.

5   [29]   Each output signal 18 from the coarse wavelength demultiplexer 16 is routed to an optical time domain demultiplexer 20. Figure 3 shows the optical signal in the time domain before entering the optical time domain demultiplexer. A number of technologies exist for realizing the optical time domain demultiplexer function, such as $LiNbO_3$ modulators and semiconductor optical amplifier switches. Before entering the time domain demultiplexer 20, a portion of the

10   signal 18 is tapped off in order to provide a means to recover the clock frequency 19 for the 40 Gbit/s signal. Although the signal-to-noise ratio in the tapped light signal is too low to permit an error free recovery of the data, it is sufficiently high to permit the recovery of the clock frequency, which is used to trigger the optical time domain demultiplexer 20. The time domain demultiplexer 20 demultiplexes the input signal or wavelength stream 18 into several time

15   domain demultiplexed wavelength streams having a lower bit-rate than the input wavelength stream 18. The sum of the bit-rates of these lower bit rate channels equals the bit-rate of the input data stream 18 to the time domain demultiplexer 20. For example, the 40 Gbit/s data stream shown in Fig. 3 is demultiplexed into four 10 Gbit/s data streams, i.e. the time domain demultiplexed wavelength streams. One of these lower bit-rate 10 Gbit/s data streams is shown

20   in Fig. 4; the pulse width is still 12.5 ps, but the pulse separation is now 100 ps. In the wavelength domain, the bandwidth of one of these 10 GHz data streams still has a 80 GHz bandwidth at the channel wavelength and residual side bands spaced at 100 GHz on either side of the channel wavelength. However, because the data rate is now only10 Gbit/s (RZ signal bandwidth 20 GHz) as compared to 40 Gbit/s data rate (RZ signal bandwidth 80 GHz), the

25   adjacent channels can be removed using a narrow band filter 24 without losing any data. Therefore the output signal 22 from the optical time domain demultiplexer 20 is passed through a narrow band optical band pass filter 24 having a bandwidth sufficiently small to remove the optical signal in the adjacent channels. This filtering action is illustrated in Fig. 5. The demultiplexed signal 26 from each filter 24 passes to a receiver 28 where the data is recovered

30   without any loss of information.